Aortic fenestration for acute or chronic aortic dissection: An uncommon but effective procedure

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Background: **Aortic fenestration is rarely required for patients with acute or chronic aortic dissection. To better define its role and the indications for its use and to evaluate its success at relieving organ or limb malperfusion, we reviewed our experience with direct fenestration of the aorta.**
Methods: **A retrospective analysis of all consecutive aortic fenestrations performed between January 1, 1979, and December 31, 1999, was performed. Fourteen patients, 12 men and two women (mean age, 59.6 years; range, 43-81), underwent fenestration of the aorta. All patients were hypertensive and had a history of tobacco use. By Stanford classification, there were three type A and 11 type B patients. In the acute dissection group (n = 7), indications for surgery were malperfusion in six patients (leg ischemia, 4; renal ischemia, 5; bowel ischemia, 3) and intra-abdominal bleeding from rupture in two. In the chronic dissection group (n = 7), indications for surgery were abdominal aortic aneurysm in 4 patients (infrarenal, 3; pararenal, 1), thoracoabdominal aneurysm in 1, hypertension from coarctation of the thoracic aorta in 1, and aortic occlusion with disabling claudication in 1.**
Results: **Emergency aortic fenestration was performed in seven patients (surgically for 6 and percutaneously for 1). Fenestration level was infrarenal in four and pararenal in three. Concomitant abdominal aortic graft replacement was performed in four patients, combined with ascending aortic replacement (n = 1) and bilateral aortorenal bypasses (n = 1). In two patients, acute fenestration was performed for organ malperfusion after prior proximal aortic replacement (ascending aorta, 1; descending thoracic aorta, 1). Seven elective aortic fenestrations were performed for chronic dissection (descending thoracic aorta, 2; paravisceral aorta, 2; infrarenal aorta, 2 and pararenal aorta, 1). Concomitant aortic replacement was performed in six patients (abdominal aorta, 5; thoracoabdominal aorta, 1). Fenestration was successful at restoring flow in all 10 patients with malperfusion. Operative mortality for emergency fenestration was 43% (3/7). The three deaths that occurred were of patients with anuria or bowel ischemia, or both. There were no postoperative deaths for elective fenestration. At a mean follow-up of 5.1 years, there were no recurrences of malperfusion and no false aneurysm formations at the fenestration site.**
Conclusion: **Fenestration of the aorta can effectively relieve organ or limb ischemia. Bowel ischemia and anuria are indicators of dismal prognosis and emergency fenestration in these patients carries a high mortality. Elective fenestration combined with aortic replacement can be performed safely in chronic dissection. Aortic fenestration is indicated for carefully selected patients with malperfusion and offers durable benefits. (J Vasc Surg 2000;32:711-21.)**

Aortic dissection is the most common aortic emergency, with an incidence double that of ruptured abdominal aortic aneurysm.[1] The natural course of type A aortic dissection has been long recognized to be rapidly lethal, mainly from aortic rupture or from cardiac complications such as acute

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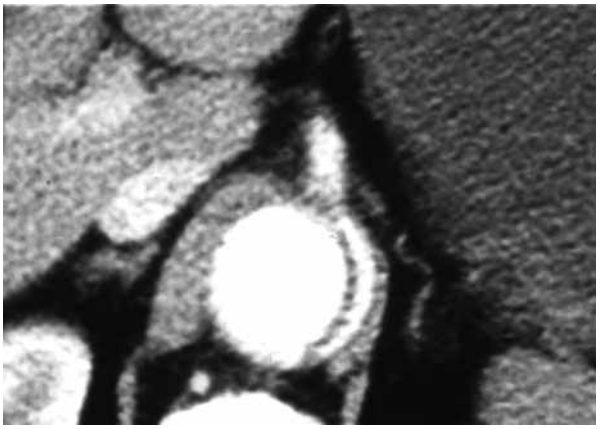

Fig 1. CT of the abdomen showing a left-sided crescent-shaped true lumen compressed by the false lumen, with decreased perfusion to the superior mesenteric artery.

Table I. Risk factors in patients with aortic dissection undergoing aortic fenestration

Risk factors	*No.*	*%*
Hypertension	14	100
Tobacco use	14	100
Peripheral vascular disease	9	64
Coronary artery disease	7	50
Prior MI	5	36
Hyperlipidemia	4	29
COPD	3	21
Chronic renal failure*	2	14
Diabetes mellitus	1	7
Cerebrovascular disease	1	7

*Chronic renal failure defined as serum creatinine level ≥ 2.0 mg/dL.
COPD, Chronic obstructive pulmonary disease; *MI*, Myocardial infarction.

tamponade or aortic regurgitation.[2] The second most common complication resulting from aortic dissection is peripheral vascular compromise, occurring in the range of 18% to 33%.[3-7] Organ or limb malperfusion is a significant predictor of early and late death.[3,5,6] Since the first successful surgical treatment, by DeBakey in 1954, of a patient with a thoracic aneurysm caused by dissection, various surgical options have been attempted to reverse malperfusion from aortic dissection.[4] The fenestration procedure consists of creating a reentry tear mimicking an "imperfect natural cure of the disease." Gurin carried out an iliac fenestration in 1935 and successfully restored limb perfusion, but his patient died as a result of renal failure.[8] The first aortic fenestration, performed by Shaw in 1955, successfully relieved limb ischemia, but the patient died of renal failure.[9] To this day, aortic fenestration is still a rarely performed procedure, and surgical series have remained very small.[10-14] Little attention had been given to aortic fenestration until recently, when endovascular techniques were proposed for the management of vascular complications from aortic dissection.[15-17]

The aims of our study were to find how often and under what circumstances aortic fenestration is indicated in patients with aortic dissection, to assess its safety and efficacy at relieving organ or limb malperfusion, and to determine its long-term durability and the risk for late aortic complications such as false aneurysm formation or rupture.

PATIENTS AND METHODS

Using the Mayo Clinic database, we identified 857 patients who had a diagnosis of aortic dissection between January 1, 1979, and December 31, 1999. From this group, 321 underwent surgical intervention. Clinical or radiographic malperfusion was present in 81 patients (25%). Fourteen patients had aortic fenestration. Medical records including imaging studies were retrospectively reviewed. The following variables were abstracted from the patients' charts: age, sex, cardiovascular risk factors, clinical presentation by symptoms, organ or limb ischemia, imaging studies, acuity and type of dissection (Stanford and DeBakey classification), method and level of aortic fenestration, need for concomitant procedures, success at relieving malperfusion, operative survival, postoperative complications, late survival, and late aortic complications. Follow-up was obtained from medical records, office visits, correspondence with referring physicians, and telephone interview. Dissection was defined as "acute" if symptom duration was less than 14 days and "chronic" if symptoms lasted more than 14 days. *Chronic renal failure* was defined as serum creatinine level of 2.0 mg/dL or greater. *Operative mortality* was defined as death occurring in the hospital without regard to the number of days after the operation it occurred.

Fourteen patients underwent aortic fenestration during the study period. There were 12 men and two women with a mean age of 59.6 years (range, 43-81 years). Table I summarizes the prevalence of cardiovascular risk factors in these patients. All patients were hypertensive and had a history of tobacco use. The prevalence of chronic renal failure was 14% (2/14). The mean preoperative serum creatinine level was 1.4 mg/dL (range, 1 to 2.7 mg/dL). By Stanford classification there were three type A and 11 type B dissections. All three type A dissections were

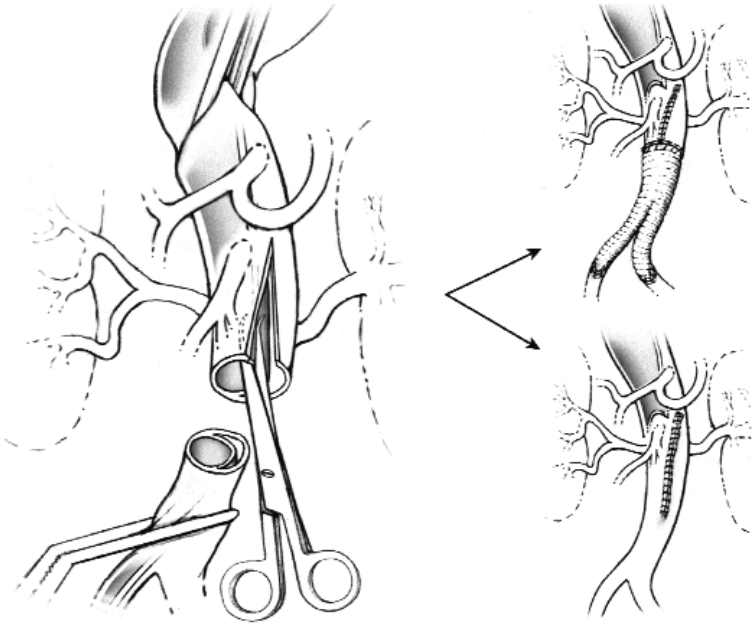

Fig 2. Schematic drawing of aortic fenestration showing infrarenal aortic transection with cephalad pararenal aortotomy and resection of the septum between the false and true lumens *(left)*. After pararenal fenestration, infrarenal aortic replacement with an aortobi-iliac graft *(top right)* or primary closure without graft replacement *(bottom right)*.

also type I by DeBakey classification. Ten of the 11 type B dissections were type IIIb by DeBakey classification, and the remaining one was type IIIa. By acuity, seven patients had acute dissection, and the other seven patients had chronic dissection. Of 14 patients, 13 underwent preoperative imaging studies (93%). The one patient without preoperative studies was rushed to the operating room with hemorrhagic shock and cardiac arrest from infrarenal aortic rupture. Ten patients (72%) had a preoperative aortogram, 9 patients (64%) had computed tomography (CT) of the chest and abdomen, 2 patients (14%) had transesophageal echocardiography (TEE), and 3 patients (21%) had transthoracic echocardiography. Overall, nine patients had more than one preoperative imaging study. At our institution, the preferred treatment for patients with type B dissection is medical management based on antihypertensive therapy and adequate pain control.

Acute dissection group. Seven patients underwent emergency aortic fenestration for treatment of acute aortic dissection (Table II). Two patients had type A dissection, and five had type B dissection. Clinical presentation was malperfusion syndrome for six patients and intra-abdominal bleeding from rupture for two patients. These two patients were operated on to stop the bleeding and had concomitant fenestration. The patient with right iliac artery rupture also had right renal ischemia. Of the 6 patients with malperfusion, 4 had lower limb ischemia (bilateral, 3), 5 had renal ischemia (anuria, 2), and 3 had bowel ischemia (Fig 1). Malperfusion syndrome occurred in two patients despite proximal aortic replacement done the day before (ascending aorta, 1; descending thoracic aorta, 1). The mean interval between malperfusion onset and fenestration was 19 hours (range, 3-48 hours). For five patients, fenestration was performed in 6 hours or less after the onset of ischemia. Abdominal aortic fenestration was performed at the infrarenal level in four patients and the pararenal level in three patients. All four patients with infrarenal aortic fenestration also underwent abdominal aortic graft replacement (straight graft in 2 and bi-iliac in 2; Fig 2). For two of these patients, additional concomitant procedures were also performed (aortobilateral renal artery bypass grafts in 1 and replacement of the ascending aorta in 1). In three patients, the proximal anastomosis was constructed with a circular felt strip to reinforce the sutures. Two of the three pararenal aortic fenestrations were done surgically, and one was done percutaneously. The two patients with surgical pararenal fenestration had had prior infrarenal aortic graft placement done for abdominal aortic aneurysm (AAA) repair. Fenestration was done in a similar fashion in

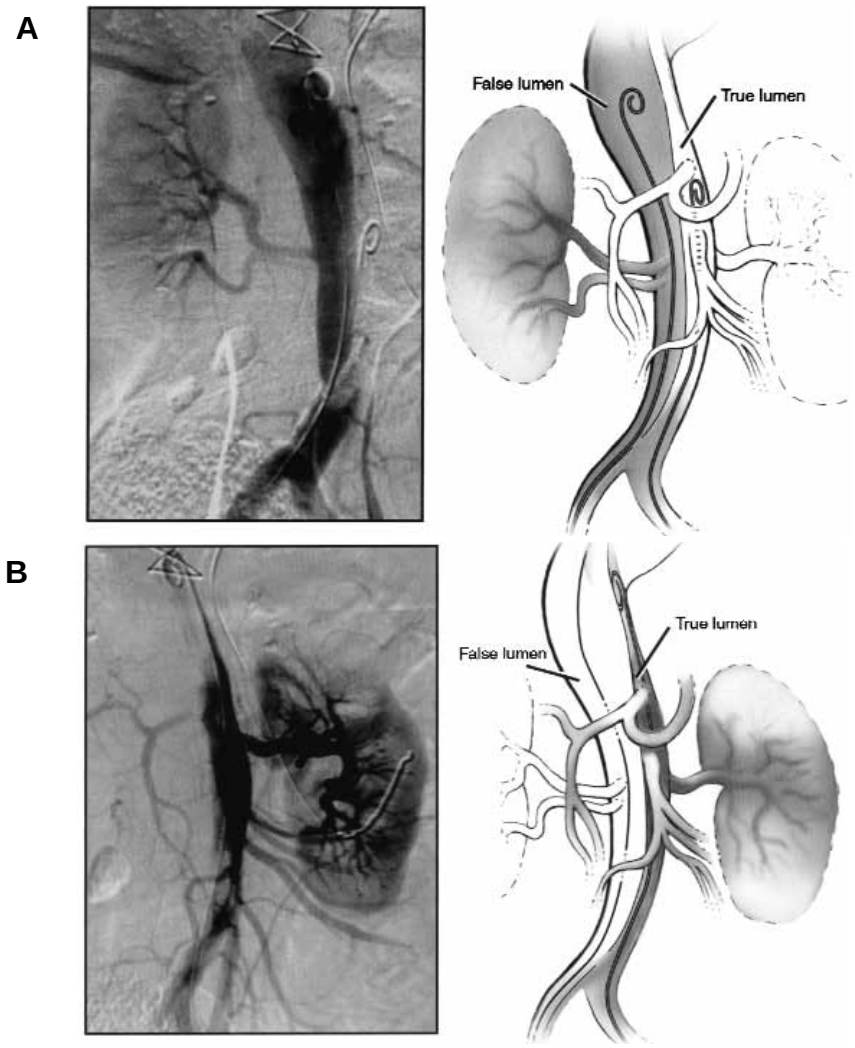

Fig 3. Injections with the catheter in the false **(A)** and true **(B)** lumens show the left renal, celiac, and superior mesenteric arteries to arise from the true lumen, and the two right renal arteries to arise from the false lumen. A pressure gradient >30 mm Hg was measured from the false to the true lumen.

both patients by transverse graftotomy with cephalad longitudinal aortotomy for pararenal fenestration (Fig 2). In the last patient, endovascular pararenal aortic fenestration was done through a bilateral percutaneous transfemoral approach with perforation of the septum, balloon fenestration (14-mm balloon), and suprarenal aortic stent placement in the true lumen above the fenestrated septum (Figs 3 and 4).

Chronic dissection group. Seven patients underwent elective aortic fenestration for treatment of chronic aortic dissection (Table III). One patient had type A dissection, and six patients had type B dissection. The primary clinical presentation was aneurysmal disease in five patients and chronic malperfusion syndrome in two patients. Two patients with aneurysm also had evidence of chronic malperfusion. Indications for surgery were 3 infrarenal abdominal aortic aneurysms (symptomatic, 2; enlarging, 1), 1 enlarging pararenal AAA, and 1 symptomatic thoracoabdominal aortic aneurysm (TAA). In the 4 patients with chronic malperfusion, 2 had bilateral lower limb claudication (one with TAA), 1 had left renal ischemia (with AAA), and the last patient had severe refractory renovascular hypertension from functional thoracic coarctation caused by the compressed true lumen. Two patients had prior proximal aortic replacement; ascending aorta (17 months) and descending thoracic aorta (54 days). Three patients had concomitant fenestration at the time of graft replacement to prevent malperfusion. Fenestration was performed in the descending thoracic

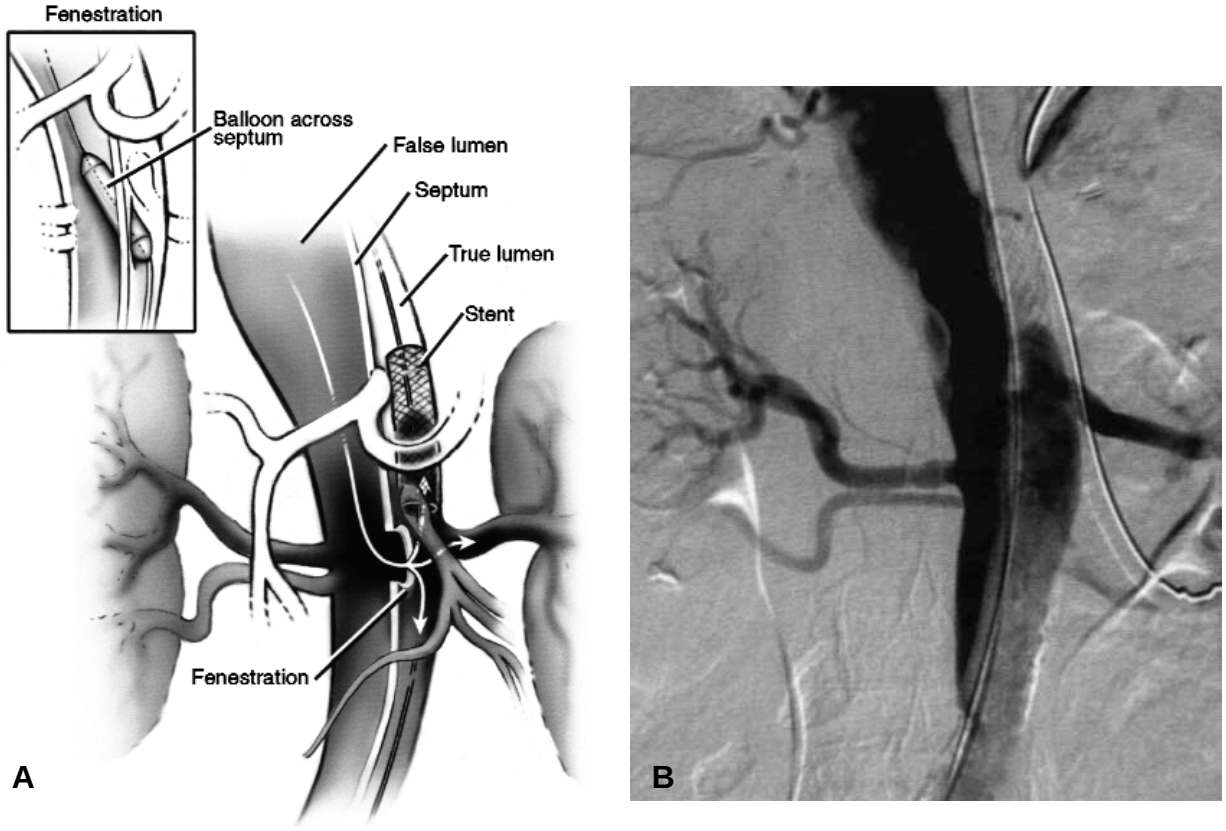

Fig 4. Fenestration was performed with the balloon advanced across the septum from the true to the false lumen *(inset)* at the level of the renal arteries **(A)**. A Palmaz stent was placed in the true lumen at the level of the celiac and opened to 12 mm to hold the aortic wall away from the visceral vessel origins. Completion angiogram **(B)** shows excellent perfusion of both lumens through the fenestration, with a gradient of 7 mm Hg from the false to the true lumen.

aorta in 2 patients and in the abdominal aorta in 5 patients (infrarenal, 2; paravisceral, 2; and pararenal, 1). Concomitant graft replacement of the abdominal aorta was done in five patients and of the thoracoabdominal aorta in one patient. Aortic cross-clamping is done at the supraceliac level for concomitant abdominal aortic fenestration and graft replacement. The juxtarenal aorta is transected, and fenestration is performed through the divided end of the aorta or with the help of a longitudinal aortotomy, which extends cephalad up to the takeoff of the superior mesenteric artery. After primary closure of the longitudinal aortotomy, the proximal anastomosis is constructed. Depending on the quality of the chronically dissected aortic wall, felt strips may be added to help with suture retention. The aortic clamp is then transferred to the aortic graft to allow visceral reperfusion and then proceed with distal anastomoses. A left renal bypass was also performed in two patients, one for dissection extension into the renal artery and the other as part of a TAA repair. In the female patient with paravisceral fenestration, a patch aortoplasty was performed at this level because of the relatively small size of the aorta to avoid causing stenosis by primary closure of the longitudinal aortotomy.

RESULTS

Early outcome. The malperfusion syndrome was relieved for all 10 patients with organ or limb ischemia (Tables II and III). Early operative survival from fenestration was 79% (11/14). To better define outcome in relation to acuity of dissection, we divided further analysis between acute and chronic dissection groups.

The operative mortality was 43% (3/7) in the acute dissection group. The timing of death was 3 days, 4 days, and 44 days, the causes of death being acute renal failure, myocardial infarction, and multisystemic organ failure, respectively. One patient seen with bowel ischemia, anuria, and right leg ischemia

Table II. Emergency aortic fenestration in patients with acute aortic dissection

Age/sex	*Presentation*	*Type**	*Level of fenestration*	*Concomitant procedure*	*Successful reperfusion*	*Hospital survival*
58/M†	Bil leg ischemia ischemic colitis	A/I	Infrarenal	AA graft	Yes	No; (MOF)
76/M‡	Bowel ischemia; anuria; R leg ischemia	B/IIIb	Infrarenal	ABI graft Aorto-bi-renal bypass	Yes	No (ARF)
50/M	Cardiac arrest; infrarenal aortic rupture	B/IIIb	Infrarenal	AA graft	N/A	Yes
56/M	R iliac rupture; R renal ischemia	A/I	Infrarenal	Ascending graft ABI graft	Yes	Yes
69/M	Bil leg ischemia; R renal ischemia	B/IIIb	Pararenal	____	Yes	Yes
81/M	Bil leg ischemia; anuria	B/IIIb	Pararenal	____	Yes	No (MI)
68/F§	Bowel ischemia; oliguria L renal ischemia	B/IIIb	Pararenal	Aortic stent	Yes	Yes

Bil, Bilateral; *AA,* abdominal aorta (straight graft); *MOF,* multisystemic organ failure; *ABI,* aortobiiliac; *ARF,* acute renal failure; *N/A,* not applicable; *MI,* myocardial infarction.
*Stanford/De Bakey.
† Prior ascending aorta replacement (1 day).
‡ Prior descending thoracic aorta replacement (1 day).
§ Percutaneous fenestration.

Table III. Elective aortic fenestration in patients with chronic aortic dissection

Age/sex	*Presentation*	*Type**	*Level of fenestration*	*Concomitant procedure*	*Successful reperfusion*	*Hospital survival*
43/M†	Symptomatic AAA; L renal ischemia	B/IIIb	Infrarenal	ABI graft L renal bypass	Yes	Yes
62/M	Bilateral leg claudication; symptomatic TAA	B/IIIb	Descending thoracic	TA graft L renal bypass	Yes	Yes
51/F	Bilateral leg claudication; aortic occlusion	B/IIIb	Paravisceral	ABF graft; patch aortoplasty	Yes	Yes
54/M‡	Enlarging pararenal AAA	A/I	Paravisceral	ABI graft	N/A	Yes
60/M	Symptomatic AAA	B/IIIb	Infrarenal	ABI graft	N/A	Yes
63/M	Enlarging AAA	B/IIIb	Pararenal	AA graft	N/A	Yes
44/M	Refractory hypertension	B/IIIa	Descending thoracic	—	Yes	Yes

AAA, Abdominal aortic aneurysm; *ABI,* aortobi-iliac; *TAA,* thoracoabdominal aortic aneurysm; *TA,* thoracoabdominal; *ABF,* aortobifemoral; *N/A,* not applicable; *AA,* abdominal aorta (straight graft).
*Stanford/DeBakey.
†Prior descending thoracic aorta replacement (54 days).
‡Prior ascending aorta replacement (17 months).

1 day after emergency descending thoracic aorta replacement underwent infrarenal fenestration combined with aortobi-iliac grafting and aortobilateral renal artery grafting for concomitant atherosclerotic renal artery stenosis. Postoperatively, despite successful renal reperfusion with adequate urine output, he required dialysis because of acute tubular necrosis and died 3 days postoperatively. The second patient had bilateral lower limb ischemia and anuria from pararenal aortic occlusion caused by true lumen compression with secondary thrombosis. He underwent pararenal aortic fenestration, which successfully relieved limb and renal ischemia. Despite renal function recovery, this patient died of a massive circumferential subendocardial myocardial infarction on postoperative day 4. The third patient, a day after ascending aorta replacement for type A dissection, was seen with bilateral lower limb ischemia and

ischemic colitis, from distal abdominal aortic occlusion caused by true lumen compression, with thrombosis extending into the iliac arteries, and this was treated with infrarenal fenestration with abdominal aortic graft replacement. Subsequently, extended left hemicolectomy had to be done for ongoing colonic bleeding from mucosal ischemia. This patient died 44 days later of a combination of sepsis and multisystemic organ failure, including myoglobinuric acute renal failure. Acute malperfusion syndrome was successfully relieved in all six patients. However, for two patients the prolonged period of ischemia led to permanent organ damage, which contributed to their deaths as described above. In all 5 patients with renal ischemia, perfusion was restored by pararenal fenestration in 3 and infrarenal fenestration in 2, including 1 who required bilateral renal bypass grafts for concomitant atherosclerotic occlusive disease. The most recent patient treated with percutaneous balloon fenestration of the pararenal aorta had immediate relief of abdominal pain from mesenteric ischemia, and the serum lactate level returned to normal. However, 6 hours later, acute ischemia of the left leg developed and she required a crossover right-to-left femorofemoral bypass graft. Despite tight blood pressure control, 7 days later she was seen with an acute onset of recurrent back and lower chest pain. A CT scan confirmed rupture of the lower descending thoracic aorta. All intra-abdominal viscera were well perfused. She underwent an emergency left thoracotomy and replacement of the lower third of the descending thoracic aorta. Because the thinned adventitia could not hold sutures at the distal anastomosis, the false lumen was obliterated and reattached with a circular felt strip. After the distal anastomosis was completed, an intraoperative ultrasound scan confirmed adequate flow in the right renal artery, which initially originated from the false lumen and was now perfused through the reentry created by balloon fenestration. Her postoperative course was uneventful, and she was discharged 8 days later. The fenestration procedure did not cause the aortic rupture, because it was located more proximally in the descending thoracic aorta and occurred 7 days later.

In the chronic dissection group, all patients survived, and the four patients with evidence of chronic malperfusion syndrome had complete relief. Two patients were seen with complications that called for reoperation. One patient had a postoperative pancreatitis and a right groin lymphocele develop, which required exploration and lymph leak ligation 20 days after aortic fenestration, with graft replacement and renal bypass graft with a saphenous vein. The second patient required reoperation for postoperative bleeding from the mid ileum, which required segmental resection 23 days after TAA repair.

Late outcome. Follow-up was complete for all 11 survivors. The mean follow-up was 5.1 years (range, 3 months to 12.4 years). All patients remained free from symptomatic recurrence of malperfusion syndrome. Ten of the 11 late survivors had postoperative imaging studies done. For these 10 survivors, the mean interval between aortic fenestration and the last CT scan on follow-up was 1.7 years (range, 1 month to 5.8 years). There was no evidence of aneurysmal formation at the site of aortic fenestration in these 10 patients. One patient was found at 12.2 years to have a large proximal descending thoracic aneurysm after Crawford type III TAA repair. A CT scan at 5.8 years had previously showed no aneurysm. Two patients died at 7.8 years and 12.4 years. The first patient died of myocardial infarction. The second patient, found to have a proximal descending thoracic aneurysm, underwent repair at another institution. Postoperative bleeding necessitated reexploration, and he died intraoperatively.

DISCUSSION

Aortic dissection can manifest itself through a wide variety of clinical presentations. The most spectacular manifestation is aortic rupture, either freely or retrograde, with acute tamponade. This has remained the first cause of mortality from aortic dissection. Peripheral vascular complications from aortic dissection can occur in up to a third of patients and increase the risk of early death.[3-7] Therapeutic options to manage peripheral vascular compromise from aortic dissection are varied, and specific treatment guidelines are difficult to establish. Mechanisms of aortic branch compromise have been well described by Crawford.[18] False lumen expansion can compress the true lumen and cause aortic occlusion or obstruction of aortic branch vessel origins. This can also lead to secondary distal thrombosis inside the aortic branch vessel. The dissection process can also extend into the branch vessel itself. It is important to consider these various mechanisms of malperfusion to understand the potential reversibility of limb or end-organ ischemia with the spontaneous reentry or the surgical redirection of blood flow. It has been well demonstrated by Fann et al[6] that up to 92% of patients with peripheral vascular compromise from acute dissection can expect spontaneous resolution after proximal aortic replacement. In their report, persistent malperfusion occurred only after central repair of type A dissection. However, among our 14 patients requiring aortic fenestration,

4 (29%) had organ or limb malperfusion after proximal aortic replacement for aortic dissection. Similar findings were reported by Elefteriades, with three of 12 patients (25%) requiring fenestration for persistent limb ischemia after ascending aorta graft replacement.[10] Therefore, limb or organ malperfusion may persist after proximal aortic graft replacement despite redirecting blood flow into the true lumen, and operative techniques for central repair may affect malperfusion incidence. Persistent or de novo malperfusion may require surgical options such as aortic fenestration or direct surgical revascularization of aortic branch vessel by reimplantation, aortic origin bypass graft, or extra-anatomic bypass graft.

The first survivor of aortic fenestration was reported by DeBakey in 1955.[19] Subsequent reports on aortic fenestration were limited to single case studies. The largest series on surgical aortic fenestration was reported by Elefteriades in 1990, with a total of 12 patients.[10] This series was later updated, and a 93% reperfusion rate was obtained in 14 patients undergoing aortic fenestration.[20] In our series, success at reperfusion was 100% (10/10). Similarly high reperfusion success rates have been reported by others.[5,11,12,14] It is therefore clearly established that aortic fenestration can successfully reperfuse ischemic limbs or organs after acute dissection.

Operative mortality of aortic fenestration in patients with acute dissection remains high, ranging from 21% to 71%.[11,20] In this series, operative mortality for emergency fenestration in acute dissection was 43% (3/7). The primary cause of death appears to be multisystemic organ failure or renal failure.[5,10,11] This was the case for two of the three deaths. This emphasizes the problem that permanent ischemic damage may have occurred by the time malperfusion syndrome is recognized and despite successful reperfusion by fenestration, irreversible end-organ ischemia has occurred and led to renal failure or multisystemic organ failure. Cambria et al reported a 66% mortality rate for abdominal fenestration due to multisystemic organ failure.[5] At the opposite of this spectrum, aortic fenestration done electively in patients with chronic dissection can be done safely with no mortality even when combined with aortic graft replacement (6/7) (Table III). From our experience with emergent fenestration in acute dissection (Table II), bowel ischemia and anuria were associated with very high mortality rates, of 66% and 100% respectively. Looking at all five 5 patients with renal ischemia, mortality rate was 40% but did increase to 100% if patients were anuric preoperatively (Table II). These two anuric patients had a 48-hour diagnostic delay between malperfusion and fenestration. Four of the five patients with a 6-hour or briefer interval between onset of ischemia and fenestration survived without permanent organ damage. A similar negative effect of mesenteric and renal ischemia on survival was found by other authors.[5,6] Cambria et al[5] found an 87% mortality rate for mesenteric ischemia and 50% for renal ischemia in patients with aortic dissection. Fann et al[6] also found a 50% mortality rate in patients with renal ischemia from aortic dissection. Improved outcome has been reported in anuric patients, confirming that the duration of ischemia defines the prognosis.[14]

Although little attention has been paid to surgical techniques of aortic fenestration, multiple options do exist and have been reported by different authors. Elefteriades et al[10] described a retroperitoneal approach, with complete aortic transection at the infrarenal level, excision of the septum, distal obliteration of the false lumen, and primary end-to-end reanastomosis or short Dacron interposition graft. Webb and Williams[14] reported their experience with abdominal aortic tailoring, an extensive fenestration of the paravisceral aorta that offers the advantage of improved management of the visceral vessels when involved by the dissection. In our experience, we favor transperitoneal over retroperitoneal approach to allow better exposure of the abdominal aorta and all its branches as well as to assess bowel reperfusion and rule out bowel necrosis. Fenestration was not performed in aneurysmal aorta. When aortic graft replacement is needed, transverse aortotomy is favored over longitudinal. However, longitudinal aortotomy at the pararenal level offers better visualization of superior mesenteric and renal arteries ostia and easier access to perform paravisceral aortic thrombectomy if the false lumen has filled with thrombus as occurred in half of our patients with acute malperfusion. If no thrombus is present in the pararenal aorta, aortic fenestration can be performed at the infrarenal level and will likely successfully reperfuse the lower limbs distally and the renal and visceral vessels proximally. Exposure of the pararenal aorta requires cephalad retraction of the pancreas, and the left renal vein is not divided but mobilized by dividing its branches.

Endovascular techniques are now being applied to treat peripheral vascular complications of aortic dissection. Williams et al[15] reported successful relief of mesenteric ischemia from subacute aortic dissection by percutaneous balloon fenestration. Despite this reperfusion success, the dissected aorta showed progressive enlargement, necessitating thoracoabdominal

aortic replacement 6 weeks later. The Stanford group reported their initial experience with the use of aortic branch vessel stenting in the management of patients with vascular complications from acute and chronic aortic dissection.[21] They reported a 20% procedural mortality rate (1/5) from bowel ischemia caused by atheroembolization. Slonim et al[17] used endovascular techniques to treat peripheral vascular complications of aortic dissection in 22 patients. Successful reperfusion was achieved in all patients, with a procedural mortality rate of only 4.5% (1/22). Six of these patients underwent percutaneous balloon fenestration. However, they had an ischemic recurrence rate of 14% (3/22), necessitating further intervention. Williams et al[16] recently reported their endovascular experience with 24 patients with peripheral vascular complications from aortic dissection. They reported a 92% success rate at restoring flow into compromised branch vessels. However, they had a 25% 30-day mortality rate and had an immediate ischemic recurrence rate of 8% (2/24). After aortic balloon fenestration, 4 patients had significant complications from the false lumen: rupture, 2; expansion, 1; paraplegia from retrograde thrombosis, 1. Our endovascular experience is limited to one patient who had immediate relief of mesenteric and renal ischemia by percutaneous balloon fenestration and aortic stenting, but developed two separate complications of leg ischemia and delayed false lumen rupture. Such complications in our patient and other patients reported in previous series raise the question that the relatively smaller size of reentry created by balloon fenestration compared to surgically may only partially decompress the false lumen and predispose to ischemic recurrence or false lumen expansion or rupture. Nevertheless, endovascular fenestration remains an attractive procedure in critically ill patients with renal and mesenteric ischemia because it rapidly relieves malperfusion syndrome. Patients with organ malperfusion can be brought into the angiography suite to establish the diagnosis of branch vessel compromise. Endovascular techniques such as balloon fenestration or branch stenting can then be applied immediately, avoiding the need for further surgical interventions. Endovascular fenestration is most useful for the rapid relief of organ malperfusion and may be part of a staged approach in patients with combined organ malperfusion and distal lower limb ischemia. In this clinical setting, endovascular fenestration would be performed to relieve mesenteric or renal ischemia and could be followed by a femoral thrombectomy with or without crossover femoral-femoral bypass graft if needed.

Surgical fenestration of the aorta is a durable procedure with no late recurrence of malperfusion. This experience is also shared by Elefteriades et al,[10] who reported no late aortic or ischemic complications after aortic fenestration. In our series, there was no false aneurysm formation at the fenestration site, as confirmed in 10 of the 11 survivors who had postoperative imaging studies. When these series on surgical fenestration are compared with the experience of Williams et al, it would appear that after percutaneous balloon fenestration the likelihood of having subsequent late aortic complications related to further expansion or rupture of the false lumen may be greater than when fenestration is done surgically. The main advantage of percutaneous fenestration is to offer quick restoration of perfusion with minimal delay. More experience and longer follow-up studies are required to better address the durability of endovascular fenestration.

Aortic fenestration has the advantages of directly relieving organ or limb ischemia in a faster way than by aortic graft replacement or bypass to the branch vessel. It is also easier to tolerate, by avoiding thoracotomy, thoracic aortic cross-clamping, and the prolonged visceral, renal, or spinal cord ischemia from aortic replacement. The key issue for aortic fenestration is careful patient selection. In our experience with 857 patients undergoing treatment of aortic dissection over a 21-year period, aortic fenestration was required for only 14 (1.6%) of the patients. This extremely small ratio of patients undergoing aortic fenestration stresses the importance of patient selection. Aortic fenestration is indicated to relieve malperfusion syndrome from aortic dissection in patients with mesenteric or renal ischemia in combination with bilateral lower limb ischemia. Patients with unilateral leg ischemia would preferentially be treated by crossover femorofemoral bypass graft. Patients with acute type A aortic dissection would first undergo proximal repair with ascending aorta replacement, as the majority would then show resolution of peripheral vascular compromise. The criteria that mandates fenestration are the presence of organ or bilateral lower extremity malperfusion caused by true lumen compression with branch vessel compromise or functional aortic occlusion with or without concomitant thrombosis. For patients with malperfusion from acute dissection, the endovascular approach should be considered the first line of treatment because it can offer rapid relief of malperfusion at the time of the diagnostic aortogram. Surgical fenestration must be considered first if branch vessel compromise or aortic occlusion are complicated by intraluminal thrombosis or if the patient has an indication for aortic graft replacement. The ideal management of

patients with significant bowel ischemia from acute type A dissection remains controversial. It may be reasonable to consider percutaneous balloon fenestration to expeditiously relieve mesenteric ischemia before proceeding with proximal aortic repair, as suggested by Deeb et al.[22]

CONCLUSION

Aortic fenestration is a simple, useful, and effective procedure that can be used to correct malperfusion syndrome caused by aortic branch vessel compromise from aortic dissection. Bowel ischemia and anuria are indicators of a dismal prognosis. Emergent fenestration in these patients carries a high mortality, which may be related to the duration of ischemia. Endovascular balloon fenestration is an attractive procedure for its rapidity at relieving organ ischemia, but further experience and longer follow-up are needed to better define its place in the management of malperfusion. Elective fenestration, combined with aortic graft replacement, can be performed safely in cases of chronic dissection. Late ischemic recurrence and aortic complications at the site of aortic fenestration are rare. In carefully selected patients with aortic dissection and secondary limb or organ malperfusion, aortic fenestration is effective and offers durable benefits.

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DISCUSSION

Dr Samuel R. Money (New Orleans, La). Thank you Dr McIntyre. I'd like to thank Dr Panneton and his colleagues for sending me the paper early enough to review. Actually, I'd like to thank them. This is the first time, I think, I've ever received a paper for review that I got on time, so thank you for that Dr Panneton.

This is a very interesting series, and it's a series that we've come to expect from the vascular group at the Mayo

Clinic. This is a huge series that most of us will never really grasp. It's 857 patients with aortic dissection, 321 who required surgical repair, and of these, 14 went on to aortic fenestration. Just by some simple math, that's a little less than 5% that went on to fenestration. First of all Jean, is it a good operation? Is it technically easy? And is it a good operation in view of the fact that in the acute setting, you have a 43% mortality and approximately 30% in the group with chronic symptoms required reoperation?

Question two is why fenestration? Basically, what is your decision tree to get to fenestration if you have 321 patients who require surgical repair and only 14 or less than 5% go on to fenestration? When do you decide to fenestrate somebody?

And I guess the third question is really, what's the future? What is the state of the art today for acute aortic dissection? Is it graft replacement? Is it fenestration? Or is it a percutaneous fenestration that is starting to win the battle in my institution?

I thank you for sending me the paper, and I look forward to your comments.

Dr Jean M. Panneton. Thank you Sam. First of all, it is a good operation as long as you select the patient carefully, and that is basically what the manuscript stresses: out of over 800 patients, only 1.6% of patients eventually required fenestration.

How are the patients selected? Well, first of all we believe that if a patient has a type A dissection, the proximal aortic repair will take care of business and will relieve malperfusion, and it's exactly what happened in the overwhelming majority of our patients. I don't have all the complete data on these patients. We're still actually reviewing this. But no doubt it will be in the range of at least 95% of patients that have correction of malperfusion by proximal or more central aortic replacement, and I think that's the first place to go. Now if a patient has only unilateral limb ischemia for example, I think all of us will just simply perform an extra-anatomic reconstruction by a crossover femoral-femoral graft. So those patients were selected for fenestration because they usually had a combination of bilateral lower limb ischemia with the presence of organ ischemia, either bowel or renal or a combination of all three possibilities. That is basically the patients that required fenestration. Now some of these patients also had graft replacement. Two patients also had rupture, one of them the iliac artery, one from the aorta, and fenestration was combined with a graft replacement.

What is the place of endovascular techniques in patients with vascular compromise? I think it's going to have a definite place. Two groups have reported extensively on that from Stanford and from Ann Arbor. They have a periprocedural mortality rate from about 5% for the Stanford group to 25% for the Ann Arbor, and in that group their proportion of acute cases was greater than their chronic cases, which makes a big difference for their result. Despite that, these endovascular techniques had an ischemic recurrence rate in the range of 10% to 15% compared with no ischemic recurrence in our patients. Furthermore, they also seem to indicate that there was a higher likelihood of eventual false lumen problem, such as further expansion requiring eventual graft replacement. One patient in their series also had retrograde thrombosis of the false lumen leading to paraplegia, and they also had some cases of false lumen rupture. Actually, our endovascular patient that we did, that's the only case that we did endovascularly, and I'm sure we'll do more and more this way, but this patient presented 7 days later with a descending thoracic aortic rupture after the successful endovascular fenestration. So it relieved the malperfusion, but one question that arises is, is it possible that because the balloon fenestration creates a smaller reentry site compared to a more extensive surgical fenestration that it makes the patient more likely to have early or, anyway, short-term complication from the false lumen? We don't have an answer for that, and we'll need basically more experience and longer follow-up to know what is the true place of endovascular techniques for these patients.

Now our mortality in the acute setting is definitely high. We have about 43% mortality. Others have had the same problem, too. That when you treat patients with peripheral vascular compromise with acute dissection, mortality increases up in the range of 30% to 40%. In fact, if you have patients with renal ischemia, the group from Stanford and the group from Mass General have shown a 50% mortality rate. If you look at patients with mesenteric ischemia, the group from Mass General also showed an 87% mortality rate for bowel ischemia in combination with acute dissection. It is a big problem because most of the time, it is diagnosed late and the organ damage is already done and the cascade of multisystemic organ failure has already started.